Fire Management Strategies for Wilderness and Other Protected Wildlands: The Potential Contribution of Landscape-Scale Analyses of Fire History

Final Report

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Lisa J. Graumlich
Big Sky Institute
Montana State University
406/994-5320
lisa@montana.edu

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Carol Miller
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Overview of Project

The history and future of fire as a disturbance process in wilderness and other protected areas is highly relevant to the development of fire management strategies. At local and regional scales, it is widely speculated that fire exclusion in fire-prone ecosystems during the 20th century has caused changes in forest structure and composition. These changes, in turn, are thought to be responsible for increasing the risk of widespread wildfire. In order to manage forest ecosystems, we must address the following questions:

- How significantly has 20th century fire exclusion reduced fire frequency?
- What was the spatial and temporal variability of pre-20th century fire as compared to 20th century patterns?
- How did climatic variability, especially severe and/or prolonged droughts, affect pre-20th century fire regimes?

In this report, we address these questions and place them in the context of a larger discussion of climate and fire in natural areas. Our strategy is to meld our direct research findings in Yellowstone National Park and Glacier National Parks with the work of others in and around wilderness and natural areas in the western United States.

The report is divided into three sections:

1. Climate, fire and natural areas: Implications of decadal-scale climate variability for understanding wildfire in wilderness and natural areas (overview)
2. A vulnerability model for understanding wildland fire as a human-environment system (paper to be submitted as Kipfer and Graumlich)
3. Climate change and wilderness management: emerging issues (Report from a workshop held in conjunction with the 8th World Wilderness Congress 2005)

Section 1. Climate, fire and natural areas: Implications of decadal-scale climate variability for understanding wildfire in wilderness and natural areas

There is a growing consensus that the interaction between climate, fuels and wildfire frequency and severity is complex. Historical studies that include pre-20th century fire scars and long-term stand dynamics continue to make a strong case for unnatural fuel accumulation and increasingly large, severe wildfires in the dry ponderosa pine forests of the US Southwest and in the mixed conifer, lower elevation forests of the Sierra Nevada (Moore et al. 1999, Caprio and Swetnam 1995). In contrast, there is strong evidence that subalpine forests (e.g., mesic spruce – fir forests, drier lodgepole pine forests) throughout the western US (but especially in the northern Rocky Mountains) are characterized by extensive, stand-replacing fires that occur at long intervals (i.e., one to multiple centuries; Romme 1982, Kipfmueller and Baker 2000, Veblen 2000). Intermediate between these two end members of a continuum are mixed-severity fire regimes at mid-elevations where complex topography creates a rich mosaic of moisture regimes and forest types (Ehle and Baker 2003, Schoennagel et al. 2004).

Given this variation in the spatio-temporal structure of fire regimes, the relative effects of fire exclusion vary across landscapes and regions (Schoennagel et al. 2004). In areas characterized by low severity fire regimes and significant increases in surface fuels, a mandate for restoration of fire as a process is clear. In wilderness areas characterized by high severity fire regimes, research to date suggests that 20th century fire exclusion has had little affect on ecological processes. ***However, decadal scale climate variability may have enhanced or negated the actual impacts of long-term fire exclusion and is a source of uncertainty both in interpreting the past and in looking towards the future.***

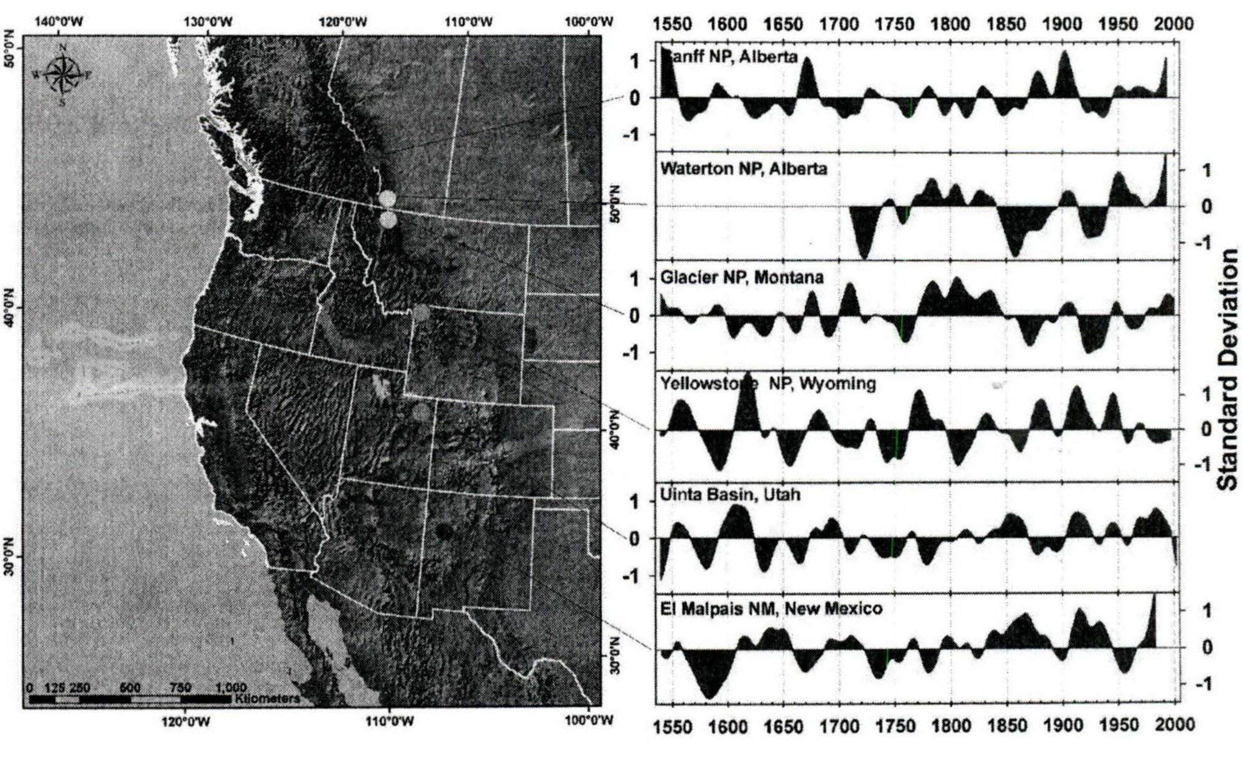
The relationship between climate and infrequent, high severity fires in subalpine forests outside the semi-arid Southwest is particularly challenging to understand because small sample sizes of 20th century events preclude strong inferences. However, we can establish that typically such fires exhibit regional synchrony related to synoptic-scale drought events (Romme and Despain 1989, Kipfmueller and Baker 2000, McKenzie et al 2004). There is evidence that these synoptic scale droughts are at least weakly associated, in turn, with organized anomalies in Pacific sea surface temperatures (i.e., El Nino cycles (ENSO), the Pacific Decadal Oscillation (PDO)). One of the two studies to tackled the question of associations between drivers of regional drought and past fire is that of Hessl et al. (2003). Hessl and colleagues identified similar spectral characteristics between summary statistics of numbers of trees scarred by fire at a network of sites in the state of Washington and times series of ENSO and PDO. The findings of Schoennagel et al. (2005) emphasize that the co-occurrence of ENSO and PDO can be critical. For example, Landlord Ninas that occur during negative phases of PDO are strongly associated with fires in Rocky Mountain National Park, and by extension, a broad region in the Northern Rockies.

In this project we focused on seeking a better understanding of long-term climate variability, especially drought, its relationship to indices of sea surface temperature anomalies and the occurrence of high severity fire in subalpine forests. We develop two case studies of fire-climate relationships at decadal time scales for Yellowstone National Park and for Glacier National Park. We conclude by reflecting on the challenges of managing fire in the context of decadal-scale droughts.

Evidence for decadal-scale drought in the Western US.

Networks of tree-ring based moisture reconstructions from the Rocky Mountains (Figure 1) indicate strong regional expression of long-duration drought and pluvial anomalies. Regional- to subcontinental-scale synchrony of moisture regimes during strong and persistent drought/wet events, and the consistency of decadal to multidecadal modes throughout the Rockies (Gray et al. 2003; Pederson et al. 2006), suggest that a common mechanism drives the spatial and temporal expression of precipitation variability in these regions. The observed modes of variation most likely extend from complex ocean-atmosphere teleconnections associated with the Pacific Decadal Oscillation (20-30 yr modes of variation; see Mantua and Hare, 2002) and Atlantic Multidecadal Oscillation (60-80 yr modes of variation; Enfield et al., 2001; Gray et al., 2003; McCabe et al., 2004).

Figure 1. (Left) Location of tree-ring based precipitation and drought reconstructions used in comparison of moisture conditions along a north to south Rocky Mountain transect in Pederson et al. (2006). (Right) Tree-ring based reconstructions of moisture anomalies. Each series has been normalized and smoothed using a 25 yr cubic spline to highlight the prominent 20 to 30 yr frequencies identified by in Pederson et al. (2006) as the dominant mode of variability in these series.

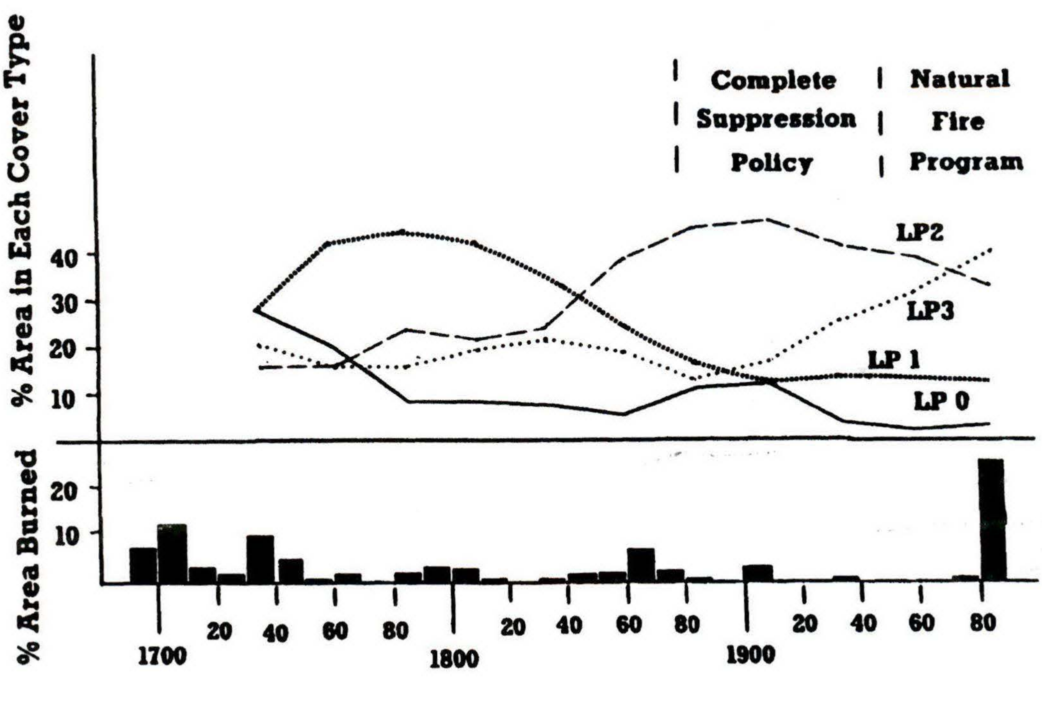


Decadal-scale climate and fire in Yellowstone and Glacier National Parks.

Such ocean-atmosphere linkages provide a means for entraining fire and other climate-related disturbance processes over regional to sub-continental scales. Swetnam and Betancourt (1998), for example, documented how droughts related to ENSO cycles appear to synchronize fires and subsequent establishment at regional scales in the Western US using data aggregated by state. In this section, we synthesize previous studies of fire history with new information from our research group on the nature of decadal-scale climate variability with fire history data from Yellowstone and Glacier National Parks.

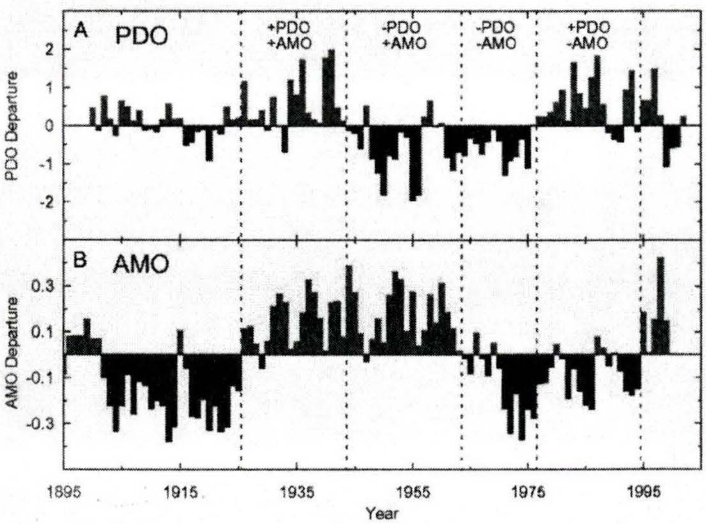
Historical studies of fire in Yellowstone National Park have focused on placing the 1988 fire in context (Romme and Despain1989, Tinker et al. 2003). These studies emphasize that the 1988 fire, although unprecedented in the 20th century, is part of a fire regime in which infrequent, stand-replacing fires dominate (Figure 2). Little interpretation was made of the nature and causes of the early 1700s fire, in part because the paleoclimatic information to interpret those events was not available.

Figure 2. Percentage of area burned by decade in the subalpine forests of the south central portion of Yellowstone National Park as adapted from Romme and Despain (1989). The fire dates are inferred from stand establishment dates obtained by coring a sample of trees and determining pith dates. The establishment dates were corroborated by fire-scarred cross-sections.



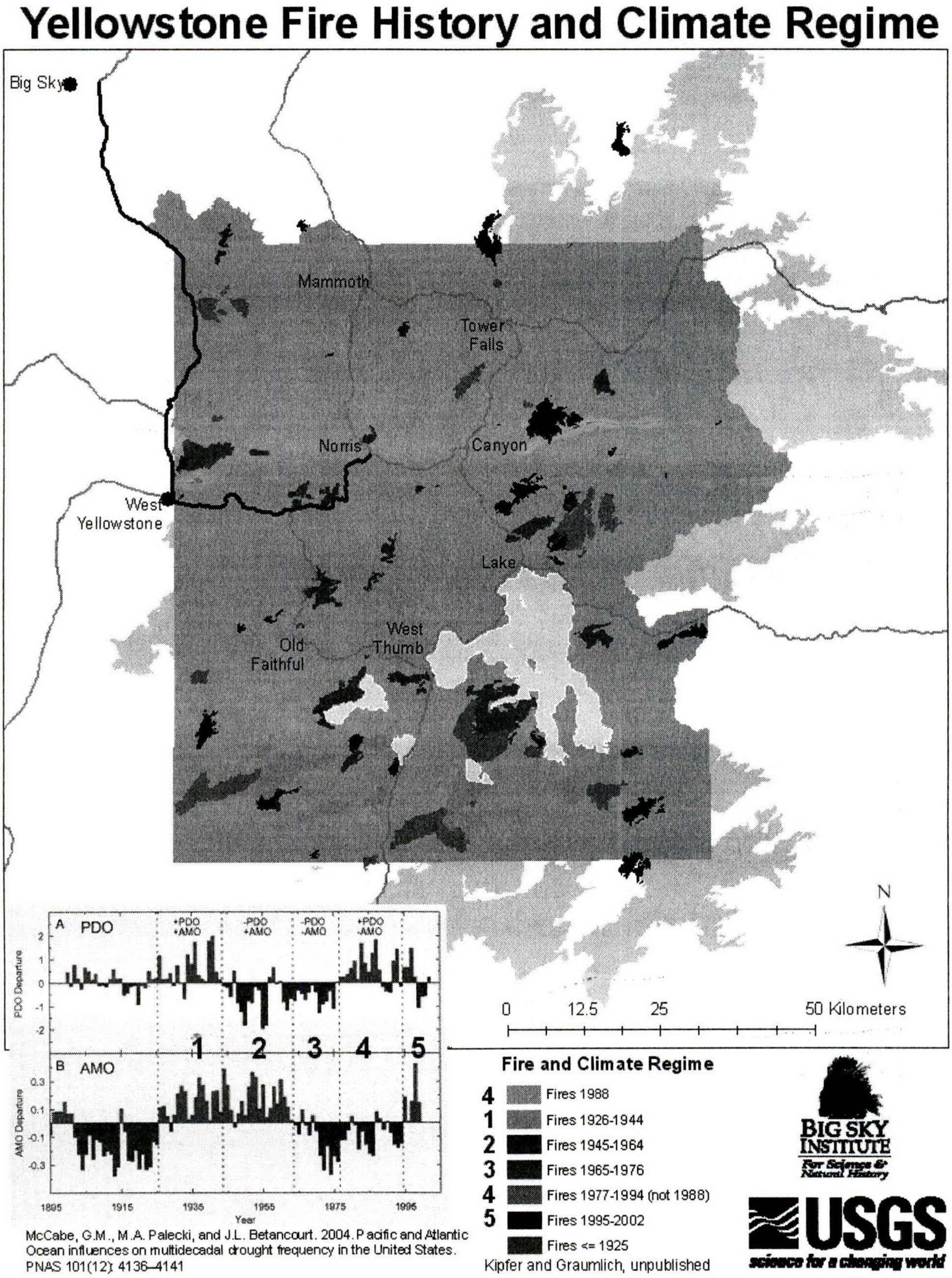
Recently, new evidence has emerged for the interaction between the Pacific Decadal Oscillation (PDO) and the Atlantic Multidecadal Oscillation (AMO) as drivers of drought in the West (McCabe et al. 2004; Figure 3). Persistent, multi-decadal drought in Northern Rocky Mountains, exemplified by the 1930s drought, is associated with the coincidence of a positive phase of the PDO and a positive phase of the AMO. Persistent pluvial (i.e., high precipitation) regimes are associated with negative phases of both indices (e.g., 1965 to 1976).

Figure 3. Time series of annual values of Pacific Decadal Oscillation (PDO) and Athe Atlantic Multi-Decadal Oscillation (AMO) adapted from McCabe et al. 2004.



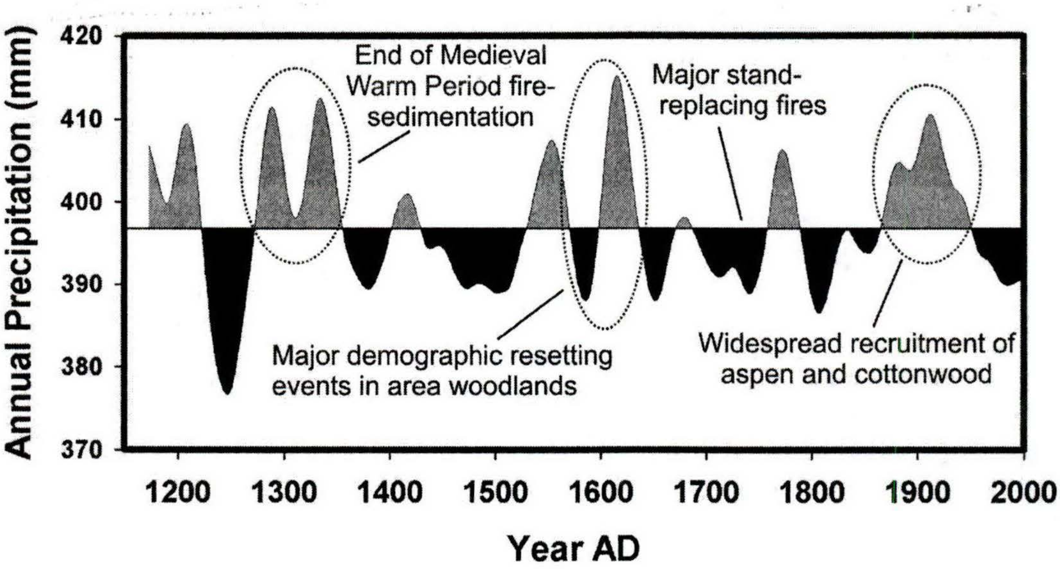
We investigated the relationship between PDO and AMO as drivers of fire in Yellowstone by aggregating fire event data representing all forest types from the Yellowstone National Park digital fire atlas (Despain, personal communication) in bins associated with the McCabe et al. climate episodes and mapped the perimeters of each event (Figure 4). We mapped the 1988 fire as its own mapping category given the size of the event. Qualitatively, the resulting map shows the largest number of fires and the greatest area burned (excluding the 1988) event occurred during the period from 1926-1944. Conversely, the extended pluvial period from 1965 to 1976 is associated with only two relatively small fire events. The area burned from 1965 to 1976 is much less than in subsequent decades when, arguably, fire suppression was more active and effective. In general, across all forest types, area burned annually in YNP correlates with climate variability; management regimes (e.g., fire exclusion) do not correlate with annual fire behavior. And, importantly, climate was not constant through the 20th Century, and forest disturbance regimes appear to have responded to climate variability throughout this century.

Figure 4: Fire history and climate regimes in Yellowstone National Park.



Preliminary comparisons between reconstructed precipitation and existing records of major YNP disturbance events and landscape transitions (Fig. 5) suggest that decadal to multidecadal precipitation variability has been a major force in shaping the region's modern landscapes.

Figure 5. Major disturbance events and landscape transitions in the Greater Yellowstone Area (after Romme et al. 1995; Meyer and Pierce 2003; Larsen and Ripple 2003) related to precipitation regimes reconstructed by tree rings (Gray et al. in review). Precipitation data are the 60-yr smoothed series shown in Figure 1.



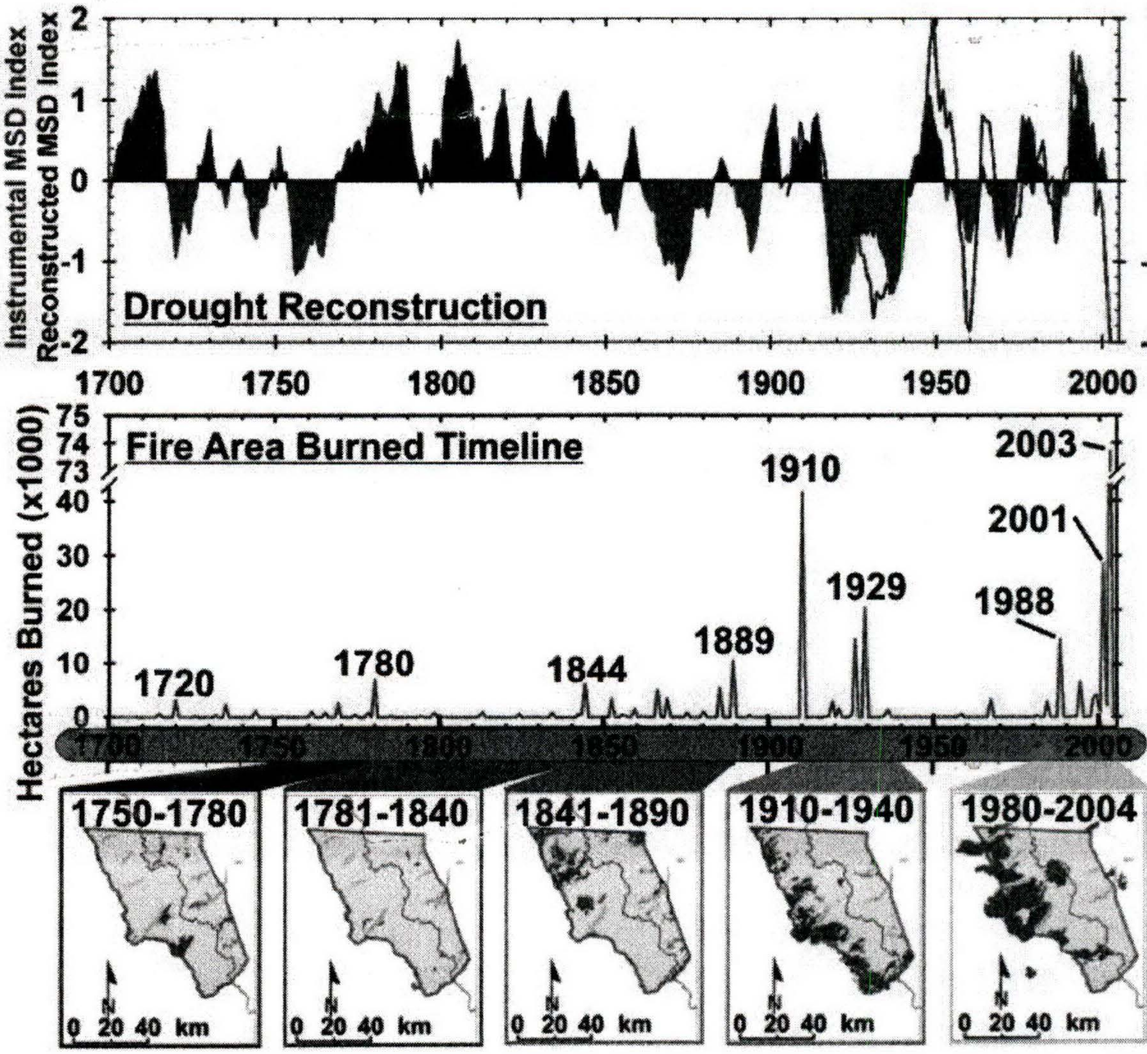
Decadal-scale variability in moisture regime is also a prominently expressed at Glacier National Park over the past five decades (Figure 1 and Figure 6 from Pederson et al. 2006). The period spanning A.D. 1670 to 1850 was characterized by many long-duration, high intensity pluvial events that correspond with the height of the Little Ice Age (LIA; ~1300-1850 A.D.). This period of generally cool and wet summers was unsurpassed by any other wet regime in the instrumental or proxy record. Since the middle of the 19^{th} century, however, our reconstruction indicates that summer drought regimes have generally been more severe than those in previous centuries. Consistent with the findings of Cook et al. (2004), Glacier NP and much of the West has again shifted to a severe drought phase, though conditions abated somewhat in 2004.

Persistent shifts in moisture regimes related to decadal and multidecadal climate variability appear to be a major driver of fire in Glacier NP (Figure 6).. We characterized the long-term pattern of fire in Glacier NP by compiling records of historic fire extent and frequency from Barrett (1982, 1986, 1988, 1993) and Key (1984) along with the

current fire database provided by (and maintained by) Glacier NP. The fire history dataset is most useful for observing the frequency of fires through time. Due to the extent of late-19th and early-20th century fires, estimates of areas burned for previous centuries are confounded, and may be underestimated by an unknown order of magnitude (Barrett, personal communication).

On annual and inter-annual time scales, fire within Glacier NP is undoubtedly driven by summer drought and possibly snowpack conditions. For example, the major fires of 1910 resulted from extreme summer drought conditions and average snowpack during the year of the fire events. When viewed in the context of the past three centuries, however, decadal and longer persistence in summer drought and winter snowpack conditions emerge as the major driver of fire regimes. The periods from the 1780s to the 1840s and the 1940s to the 1980s, for example, had generally cool and wet summers coupled with high winter snowpack resulting in extended (> 20 yr) burn regimes characterized by small, infrequent fires with relatively little area burned. Conversely, decadal and longer couplings of low snowpack and droughty summers resulted in burn regimes characterized by frequent, severe fires and large total area burned (e.g. 1910 to 1940, 1980s to present).

Figure 6. Relationship between Glacier NP inferred winter snowpack (May 1st SWE), and fire area burned) back to A.D. 1700 adapted from Pederson et al. 2006). (a) Measured Spring snowpack (May 1st SWE) anomalies (1922-present) and average annual instrumental and reconstructed PDO anomalies (1700-2000). Each time series was normalized and smoothed using a 5 yr running mean to highlight decadal variability. For ease of comparison the instrumental and reconstructed PDO index was inverted due to the strong negative relationship between PDO anomalies and May 1st snowpack. (b) Fire area burned timeline for the Glacier NP region spanning A.D. 1700-present. Timeline is presented with maps exemplifying fire activity using decadal snapshots in time over periods corresponding to interesting winter and summer precipitation regimes.



Summary and Conclusions

In summary, these findings offer intriguing evidence that severe (i.e., stand-replacing) fires in the Northern Rockies are related to decadal-scale climate variability. The long-term record shows multiple decades of low fire activity followed by clusters of high fire activity (and larger areas burned) in what could be described as regime-like behavior. This regime like behavior of climate-driven ecosystem processes is increasingly recognized in other systems (Scheffer and Carpenter 2003, Hare and Mantua 2000).

Regime-like wildfire behavior in wilderness settings poses a number of challenges to managers. First, these results and other long-term reconstructions of fire dynamics call into question the conventional strategy of defining reference conditions or management targets based solely on "short" duration (< 100 yr) observational records. In addition, step-like changes from one climate regime to the next can be sudden and surprise managers who have well-honed expectations of system behavior based on professional experience. As such, persistent shifts in wildfire may be misinterpreted as resulting from management activities. Likewise such climate-related shifts in wildfire may amplify or dampen the effects of management activities. Lastly, decadal and longer persistence of drought or wet conditions can lead to management policies that, while appropriate during the current regime, may not be robust under subsequent climates. Overall, greater awareness of regime-like behavior must shape our understanding of options for managing fire in wilderness and natural areas.

Section 2: A vulnerability model for understanding wildland fire as a human-environment system

Introduction

Wildfire is a challenging and ongoing issue that puts human society in direct conflict with fire-adapted ecosystems. Globally, fire is the most significant and widespread natural disturbance in terrestrial biomes in terms of both total area and number of biomes affected (Lavorel et. al 2006). In these ecosystems fire is a fundamental component that directly or indirectly impacts nearly all ecosystem process and characteristics and helps to shape the landscape (Kilgore 1987).

But to simply look at fire as a natural process is incomplete. In all but the most remote locations the role of fire as a natural process has been altered by human activities. Even in natural areas and wilderness, where conceptually fire can occur as a natural process, fire exclusion is the dominant management practice (Parsons 2000). The human role in fire-prone ecosystems is not a recent phenomenon. Increasingly, we have come to understand that the role of fire in the evolution and function of fire-adapted ecosystems has come from both human and lightning initiated fires (Agee 1993; Kilgore 1987; Pyne 1982), although the magnitude and frequency of these fires is debated (Barrett and Arno 1982; Kay 1995).

Fire additionally poses both direct and indirect risk to humans and ecosystem services, ranging from timber harvests to recreation. For example, decades of fire exclusion are commonly blamed for changing forests in North America and influencing recent catastrophic fire events (Arno and Brown 1989; Covington et al. 1994), Additionally in some forest ecosystems factors such as climate changes, timber harvesting, and domestic livestock grazing may have had a more influential role in these forest changes than previously thought (Baker and Ehle 2001). One of the results is that where human populations and activities coincide with fire-adapted ecosystems and landscapes, there is an inevitable battle between letting fire occur and the significant risk that fire poses to humans and human values of wilderness. Thus, fire is both an important natural process and a potentially destructive hazard that is strongly related to human activities. This duality challenges fire policy formulation and management and leaves us with seemingly limited fire management options.

Clearly, in order to understand wildfire and effectively manage fire-adapted ecosystems, we need to understand and integrate the role of human society with our understanding of the biogeophysical system. While there have been many calls to integrate human-environment systems, successes have been hard won due to the inherent complexity of the task (Gunderson and Holling 2002; Holling 2001; Folke 2002; Liu 2001). A growing body of research has explored the impact of human activities on wildfire (Baker 1992; Cardille et al. 2001; Veblen et al. 2000), but we have yet to fully integrate feedbacks between the human and environment components as they interact across scales. The work of Lavorel et al. (2006) use a vulnerability framework to conceptualize fire as a product of human-environment interactions at scales ranging from local ecosystems to the Earth system. This paper builds on that effort by presenting a vulnerability assessment model as a framework for understanding the human-environment system as it is shaped by wildfire in and near wilderness areas. Our approach links human systems

with underlying biophysical systems within a three-dimensional vulnerability framework of exposure, sensitivity, and adaptation. After detailing the vulnerability assessment model, we apply that model to three case studies from the western United States. These case studies were selected because each represents a specific wildfire syndrome that potentially has more widespread application. In addition, we assess the utility of our model in understanding the dynamics of our case study systems by looking at how the climate and human social/economic systems cause vulnerability shifts, altering regional vulnerabilities to fire. Vulnerability, as a framing concept, provides a unique view of wildfire in the western United States that has the potential to shed light on the various policy dilemmas associated with wildfire and wilderness.

Wilderness areas in the western United States provide an important vantage for such an analysis. For this study, we use the term wilderness for both lands designated as wilderness under the 1964 Wilderness Act and significant protected areas such as National Parks. While we often think of wilderness as being buffered by relatively less developed lands, wilderness in the western United States is embedded in a region that experienced the highest rate of population growth during the 1990s (Hansen et al. 2002). As such Western wilderness areas and the surrounding landscapes are areas where the natural role of wildfire is often desired yet where fire has an increasing likelihood for conflict with human settlements and livelihoods. In a June 25, 2002 editorial published in the New York Times, fire historian Steven Pyne likened wildfire to an endangered species that needs appropriate habitat. If that habitat exists, it is undoubtedly within this system of wilderness lands. Thus fire habitat, following Pyne's analogy, can be evaluated in a human-environment system of wilderness that spans local to national scales.

Wilderness fire in a human-environment system

In building a conceptual model of wilderness fire as a manifestation of human-environment interactions we are seeking to synthesize two distinct bodies of knowledge: 1) fire as an environmental process (e.g., disturbance ecology); and 2) fire as a human-mediated process (e.g., human landscapes). Traditionally, wildland fire research has evaluated fire as an environmental process; the human role of in wildland fire, beyond that of suppression, has yet to gain a similar level of consideration.

The past decade has witnessed enormous leaps in our understanding of fire as an ecological process at scales from the local to the global. Refined understanding and quantification of interplay of fuels, weather, and topography as it dictates fire risk and behavior at local (watershed) scales has given managers effective tools for understanding fire behavior and fire effects (Burgan and Rothermel 1984; Keane et al. 1989; Keane and Hann 1998; Lotan et al. 1981; Rothermel 1972).

Tools and concepts from landscape ecology have put local dynamics into larger spatial and temporal contexts, emphasizing the landscape mosaic, including factors such as vegetation pattern, fragmentation, connectivity, and climate (Miller and Urban 2000a; Turner et al. 1989; Turner and Romme 1994). At the landscape-scale the role of human activities in wildfire becomes a more significant factor (Baker 1992; Cardille et al. 2001; Veblen et al. 2000), and the application of this landscape ecological research can be

applied to questions regarding the restoration of wildlands altered by fire suppression (Baker 1994; Miller and Urban 2000b).

Paleoecological studies using tree rings and sediment records have defined pre-Euro-American settlement fire regime characteristics, a fundamental need for developing reference conditions for ecological restoration of forests altered by fire suppression or other human activities. Understanding of fire regimes is an active area of research with several areas of uncertainty related to fire history methodology (Baker 2001) and regional to global understanding (Lavorel et al. 2006). However, an important finding of paleoecology has been recognition of the role of synoptic scale climate in governing regional fire patterns in the absence of fire exclusion efforts (Swetnam and Betancourt 1998; Veblen et al. 2000). In particular, warm (el Niño) and cool (la Niña) phases of the the El Nìño-Southern Oscillation synchronize fire risk and behavior across regions at timeframes of one to five years through increased production of fine fuels or influencing drought conditions. Potentially, multi-decadal periodicities in ocean-atmosphere teleconnections (such as the Pacific Decadal Oscillation) may add additional explanation of regional fire risk and behavior (Littel 2002). Besides having important implications for forest management, these synoptic climate connections to wildfire indicate that the impacts of climate change on fire regimes could be significant (Lavorel et al. 2006).

Global change research has elucidated role of fire in carbon cycle and atmospheric chemistry. The global annual carbon flux from forest fires can influence whether an ecosystem is a carbon source or sink, leading to the hypothesis that fire suppression in the U.S. has resulted in a carbon sink (Dixon et al. 1994). Additionally, the quantity of carbon released in active fire years can approach the levels of carbon released from burning fossil fuels (Lavorel et al. 2006). Smoke can influence local weather patterns and impact air quality over large regions. The result is that fires can have significant local to global atmospheric impacts and feedbacks.

As the scale of focus shifts from the immediate and local to the long-term and global, the interaction with human systems becomes more and more critical to understanding process and pattern. In essence, human behavior, policies and institutions, as they govern ignitions, fuel management, or suppression efforts, move from being a boundary condition in a local assessment to arguably one of the most critical and dynamic variables in regional to global analyses.

In conceptualizing the interactions of human activities and fire behavior we have drawn on the literature that analyzes institutions as mediators of human interactions with environmental processes and resources. Institutions in this context are the norms, regulations, interpretations or understandings, and social organizations related to a particular activity (National Research Council 1999). In the context of wildland fire, understanding how structure and dynamics of social institutions have influenced fire regimes and land management will be fundamental for developing future policy choices. Additionally, it is unlikely that the institutional components of wildland fire simply influence biophysical systems in predictable ways. For example, short and long-term feedbacks within and between institutional and biophysical components of wildland fire add a necessary adaptive component to effective policies. As Gunderson and Holling (2002) have documented, social institutions can efficiently achieve objectives for clear natural resource management goals, but as the dynamics of the human-environment

system play out over time and space, those same efficiencies can create their own problems and hinder necessary adaptation.

For wildfire, one can draw a series of parallels with disturbance ecology in the sense that we see shifts in key variables as one changes scale. That is, the institutional context ranges from the actions of individual households or land management units to federal policies and practices. Although they do not exist as yet, global institutions that address fire may arise in the future as a part of larger agreement dealing with carbon accounting or transboundary air quality issues.

At the level of a single wilderness unit, managers address specific natural resource management needs, focused primarily on local constraints and opportunities, including funding and staffing resources. Wilderness units in turn are embedded in multi-agency and private land use settings. These wilderness landscapes add numerous stakeholders (e.g., adjacent land management units, local governments, homeowners, businesses) and unique patterns of land use scribed on the biophysical template. Federal policies provide an institutional domain, that is often slow to change and cumbersome in both its political sensitivity and resistance to change.

At individual wilderness units through wilderness landscapes, human activities impact fire-adapted systems through direct and indirect activities that alter the structure and function of ecosystems. Several studies have looked at the impacts of human activities on fire-prone ecosystems and landscapes, identifying key factors such as settlement pattern, land use, land use history, and human use (Cardille et al. 2001, Baker 1992). A wide range of indirect impacts to fire-adapted ecosystems can occur from factors such as federal policy, national media attention, land management objectives, environmental philosophy, and perceptions of ecosystem goods and services (Schullery 1997). Fire suppression is dominant response when information is limiting and or risks are deemed to high. For example, the 2000 fires near Los Alamos, the unfortunate outcome of a prescribed fire, briefly halted all prescribed fire projects nationally and reinforced fire suppression as the predominant outcome for all wildfires that season.

Conversely, ecosystems impact the geographic expression of the institutional system. Ecological values associated with wilderness attract human development. In a study of the Greater Yellowstone Ecosystem (GYE), Hansen et al. (2002) found that population growth was significantly associated with mountainous topography, forest cover, greater precipitation, and the presence of nature reserves. Further, they suggest that due to high levels of natural amenities, economies of the GYE are growing and shifting away from traditional resource extraction and agriculture. Economic growth occurred in areas such as business, engineering, healthcare, other services and nonlabor income. Thus, the goods and services provided by natural areas such as wilderness are influencing a change in human activities, ranging from choices of where to live to fundamental economic changes.

The wildland-urban interface is a geographic expression of the increasing interaction of people and wilderness areas. This zone of interaction identifies the primary exposure of humans to wildfire risk, but it is not the inclusive system of social interaction and wildfire. Smoke from large wildfires can impact entire regions. Wilderness and place values do not have a constrained geography. Even in a local context, a fire that starts

within a wilderness can move into the wildland-urban interface or vice versa. The wildland-urban interface is a fundamental component of the human-environment system, but it is only part of the system and likely one of the reasons why policy directed at this component has been largely ineffective.

Changes in how society looks at and utilizes the goods and services provided by wilderness can have significant impacts on national policy related to wildfire. Wildfire policy was historically associated with the concept that fire was a negative factor that managers needed to control. Fire suppression efforts during the late 19th and 20th Centuries impacted fire regimes throughout the western United States, although for many regions effective fire exclusion did not occur until after World War II and the application of aerial fire suppression methods. Ecosystems that have evolved under high frequency fire events were most significantly impacted by fire exclusion, while some low frequency fire regime ecosystems may have had negligible impact from fire exclusion.

By the 1980s, as our understanding of fire as a significant natural process increased, managers began to experiment with policies that let natural fires burn. This "let it burn" period essentially ended after the 1988 Yellowstone fires burned over 1.5 million acres in the Greater Yellowstone Ecosystem. Although these fires were expected within the context of natural variability of GYE fire regimes, national media attention focused on the fires as an agent of destruction of Yellowstone National Park. As the demographic and economic changes in the western United States took hold, the resulting influx of people and homes into wilderness increased the human hazards associated with wildfire. The ability for wildfire to occur as a natural process was limited because the majority of wildfires posed real or perceived risk to human settlements and communities or wilderness goods and services. Land managers were faced with managing wildfire more from the perspective of risk management than forest management, resulting in a new call for reducing wildfire hazard through fuels reduction by tools such as thinning, logging, prescribed fire, and "firewise" homes.

Although some fuels reduction projects were successful, these efforts ran into substantial resistance. Thinning efforts were actively fought by both environmentalists opposed to management practices that they attributed to a thinly veiled form of logging and local communities concerned about smoke and negative impacts to local natural amenities. Additionally, in wilderness, mechanical thinning has been opposed as an inappropriate human activity that alters wilderness values (Parsons 2000). Prescribed fire is a tool that comes with significant risk, as evidenced by the 2000 prescribed fire in Bandelier National Monument that escaped control, destroyed over 200 homes, and threatened a national laboratory.

After the 2000 fire season, there was a significant review of the 1995 Federal Fire Policy and the creation of the Cohesive Strategy for Catastrophic Fire Reduction and the National Fire Plan. These policies targeted fuels reduction and efforts to create "firewise" homes that could survive fire either directly or with firefighter assistance. By 2002, the effectiveness of these policies was put into question. The largest and most destructive fires in the history of Arizona and Colorado again brought fire and forest management policies, human settlement issues, and environmental concerns into the forefront of national media and policy makers. Decades of fire suppression, past grazing practices, environmentalists, and homeowners all received some level of public blame.

The level of attention directed at these wildland fire issues influenced even the President of the United States to propose a Federal forest health proposal that calls for a change in the legal opportunities to challenge specific actions under existing environmental law.

Knowledge gaps and limitations

We believe that an integrated human-environment system of wildfire can provide a new perspective on this issue. Fundamentally, we do not currently have a workable conceptual framework that allows an understanding of wildfire in a context that understands both ecological and social constraints and opportunities. Additionally, there are several knowledge gaps that impede understanding this system. First, we need to more clearly understand the role that both natural and anthropogenic fire shaped ecosystems and landscapes, more clearly understanding temporal and spatial dynamics of these fire regimes. Second, we need additional studies that target understanding the role of 20th Century fire suppression on fire-adapted systems. Third, we need to better understand the relative roles different fire regime drivers over different geographic and temporal scales. Finally, we need to understand social and economic factors that influence human activities and related policies in fire-adapted systems. What are the options for managing wildfire? What are the expected outcomes of various policies?

Vulnerability analysis as a tool for understanding H-E interactions

A primary question involves how wildfire operates as a coupled H-E system. We need to understand he magnitude and geography of human impact on fire regimes, while understanding the sources of vulnerability of people and forests to fire. Given the these needs, how does human society adapt to wildfire risk and how does that feed back to fire regimes? We propose a vulnerability framework as a key tool for addressing these questions.

Vulnerability framework

Our vulnerability framework is based on previous efforts to assess the vulnerability of ecological and social systems to global environmental risks. Vulnerability is a multidimensional concept that targets a specific group or unit of concern (termed the exposure unit) and seeks to identify the risk of adverse outcomes to a variety of stresses. As an emerging concept, vulnerability involves at least three elements: exposure -- the degree to which a human group or ecosystem comes into contact with particular stresses, sensitivity -- the degree to which an exposure unit is affected by explore to any set of stresses, and resilience (or adaptation) – the ability of the exposure unit to resist or recover from the damage associated with the convergence of multiple stresses (Clark et al. 2000). The concept of vulnerability fits well with the issue of wildland fire, allowing a framework within which to understand both human and environmental factors.

As a human-environment system, we identify three components within a vulnerability framework (Figure 1). Each system component has elements that fit within the vulnerability framework. Collectively, these factors describe a system where risks to wildland fire are broken down into system components and their respective role within the vulnerability context. Each element and system has feedbacks to the others, and there

can be exogenous inputs into the system such as climate change or climate periodicities such as El Nino-Southern Oscillation events. For given locations, at a given time, a specific exposure unit can be described within this framework.

The vulnerability framework has advantages over more traditional tools for looking at wildland fire. For example, two exposure units may have the same level of exposure. However, the relative contribution of different system components to that exposure may differ. Additionally, those two units may have very different sensitivities to wildland fire, or options for adaptation may differ greatly. When using wilderness as the exposure unit, these differentiations can be extremely important for developing appropriate management policies and actions. Finally, vulnerability for an exposure unit will likely change over time, but not all exposure units will change in the same manner. In the case of wildland fire in wilderness, periodic ENSO events can shift the vulnerability system in a non-linear manner. By looking at case studies, we can evaluate the utility of this framework.

We chose our case studies by first defining syndromes of wildland fire management. Syndromes describe unfavorable regional interactions between the environment and human societies that frequently operate along typical patterns (Petschel-Held 1999). These function patterns provide an interdisciplinary tool for understanding human-environment systems by identifying interactions that manifest in repeated patterns; further, it is hypothesized that a discrete number of syndromes account for our complex global environmental and development problems (Petschel-Held 1999). For this analysis, the syndrome concept is applied to identify key elements of human-environment interactions in wildland fire systems and to test the corresponding utility of the vulnerability framework.

Four wilderness syndromes represent a spectrum of the issues faced with wildland fire and wilderness (Table 1). The roles of drought and suppression fuels are widely described, but these syndromes show an additional array of factors. First, even for wildfire in one of the most extensive and remote wilderness complexes in the western United States, the Greater Yellowstone Ecosystem, cannot escape the impacts of human society (e.g., amenity migration or national media attention). In areas where the wildland-urban interface has become a dominant landscape component, sensitivity to wildfire has increased dramatically, increasing the likelihood of catastrophic fires and limiting forest management options. The 2002 fires in the Front Range of Colorado and along the Mogollon Rim of Arizona are some of the worst case scenarios. The role of prescribed fire for reducing hazardous fuels is a management tool that is not without risk. The Cerro Grande fire near Los Alamos shows how even a prescription fire set in wilderness (Bandolier National Monument) can have catastrophic consequences. Finally, each of these syndromes was significant enough to receive national media attention and have a role in shaping future national wildfire policy.

Figure 1. A framework describing interactions between sensitivity, exposure and adaptation in the context of management of wildland fire, presented from two viewpoints. The upper panel represents the expression of vulnerability in the context of ecosystem research and informs the identification of variables and description of interactions that are presented in the subsequent discussion of syndromes. The lower panel re-expresses the framework, suggesting how current wildfire management issues are related through interactions of exposure, sensitivity and adaptation.

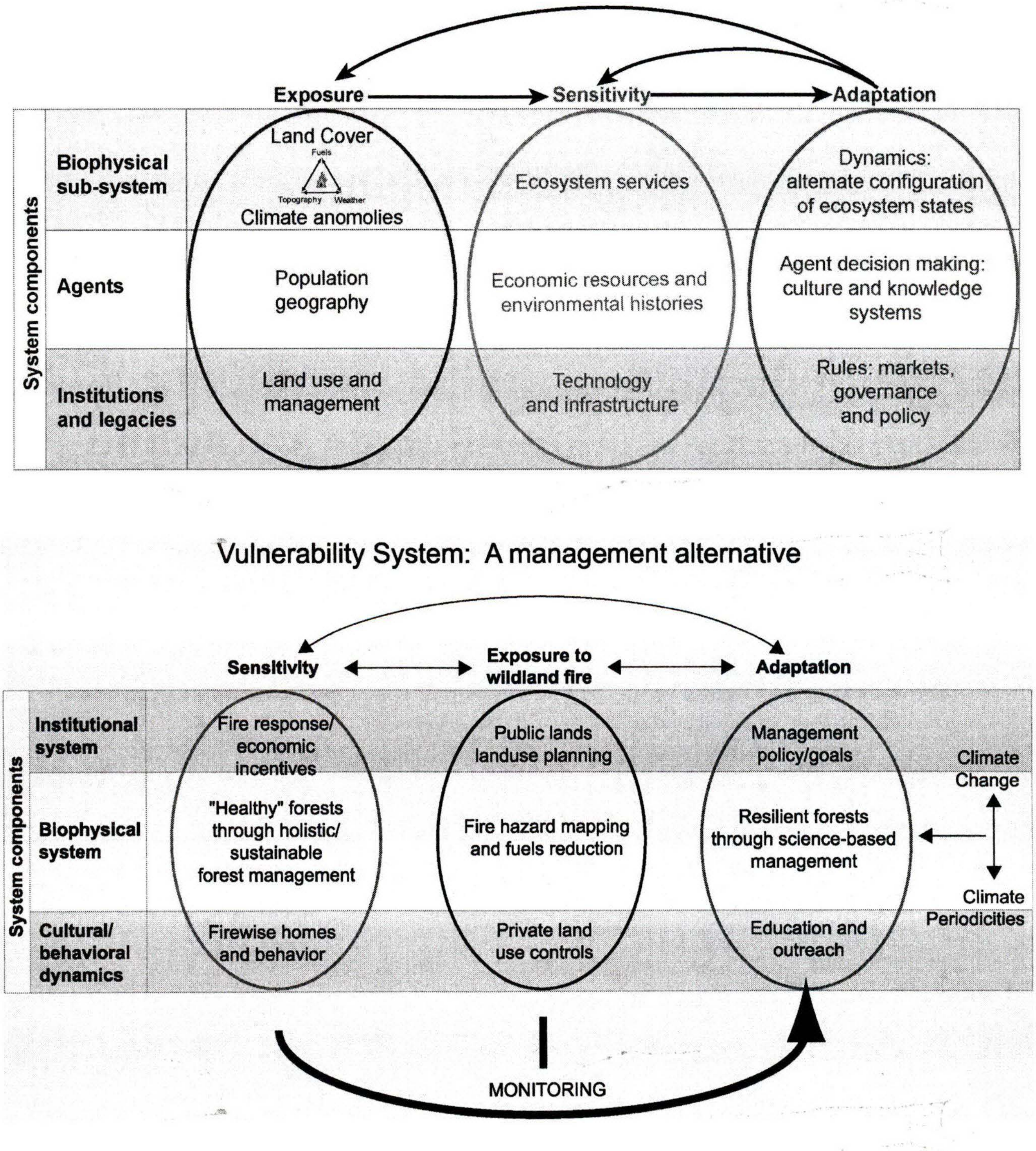


Table 1: Wilderness Fire Syndromes:

Syndrome	Exposure	Sensitivity	Adaptation
Los Alamos Syndrome (Cerro Grande Fire, 2000) – 47,650 acres burned, 235 homes burned, and 18,000 residents evacuated after planned 900 acre prescription fire in Bandolier NM escaped containment.	• Suppression fuels dominate landscape. • Uncertainties from prescribed fire, even though initiated in wilderness. • Sensitivity to drought (e.g., during La Nina events). • Amenity migration – extensive wildland-urban interface.	• Threats to a classified and sensitive National laboratory • *Few "firewise" homes.* • Communities and homeowners unprepared for realities of wildland fire.	• National media attention focused on prescribed fire issues/uncertainties, limiting prescribed fire for forest management locally and nationally. • **Influenced changes in national fire policy that targeted methods for prescribed fire and fuels reduction.** • **Local community aware of risks**
Wildland-Urban Interface Syndrome, Colorado Front Range – Rapid population growth and previous fire exclusion combine to cause extensive vulnerability to fire. The 2002 human started Haymen fire, southwest of Denver burned 137,760 acres, burned 133 homes, and cost over $39 million for suppression and protection.	• Suppression fuels a component of landscape. • Sensitivity to drought (e.g., during La Nina events). • Historical large fires correlate with a 2-3 year lag after strong El Nino events. • Amenity migration – extensive wildland-urban interface.	• Adjacent to growing metropolitan area (Denver and Front Range metro) • Important wildland recreation component of economy. • Communities and homeowners unprepared for realities of wildland fire.	• Increased emphasis on "firewise" homes. • Calls for more fuels reduction from thinning or prescribed fire. • Forest health: Potential changes for managing national forests, including calls for increased logging and streamlined environmental reviews for projects. • Little emphasis on limiting continued growth in the wildland-urban interface.
Wildland-Urban Interface Syndrome, Mogollon Rim, Arizona – Rapid population growth and previous fire exclusion combine to cause extensive vulnerability to fire. The human started Rodeo-Chediski fire near Payson, Arizona burned over 500,000 acres, burned 426 structures, and cost over $108 million for suppression and	• Suppression fuels dominate landscape. • Sensitivity to drought (e.g., during La Nina events). • Amenity migration – extensive wildland-urban interface.	• Adjacent to growing metropolitan area (Phoenix metro) • Important wildland recreation component of economy. • Significant Native American lands component with economically important logging industry • Communities and homeowners unprepared for realities of wildland fire.	• Increased emphasis on "firewise" homes. • Calls for more fuels reduction from thinning or prescribed fire. • Forest health: Potential changes for managing national forests, including calls for increased logging and streamlined environmental reviews for projects. • Little emphasis on limiting continued growth in the wildland-urban interface.

protection.			
Yellowstone Syndrome – The 1988 fires surprised a nation, resulting in increased scrutiny of fire policy and fire management in wilderness. The 1988 Yellowstone fires burned nearly 800,000 acres in the National Park and approximately 1.4 million acres in the greater ecosystem, costing over $120 million for suppression and protection.	• Suppression fuels are a minor component of landscape. • Fire regime variability and complexity in extensive Greater Yellowstone Ecosystem includes large, stand-replacing fires. • Amenity migration – exurban component of landscape.	• Yellowstone National Park is a highly valued national treasure. • Important wildland recreation component of economy • Increasing exurban development mitigated by extensive wilderness and other public lands. • Communities and homeowners unprepared for realities of wildland fire.	• Negative media attention regarding the Yellowstone National Park's "let-it burn" and post-fire "wilderness" restoration policies. • Increased national scrutiny over wilderness wildfire policy and management. • Even though fires are considered within natural range of variability, many still consider the 1988 fires catastrophic.

It is clear that these human-environment case studies of wildfire have complex driving factors and feedbacks that are illuminated by applying a vulnerability framework. Identifying the role of other factors in wildland fire is a key goal. However, there are additional dynamics to these systems. For example, vulnerability changes over time. A key question involves understanding how different systems change in vulnerability space. We hypothesize that many of the elements described by these syndromes are repeated in a variety of landscapes when dealing with wildland fire.

Vulnerability shifts

Fire-adapted systems are driven by climate system dynamics that influence the types and accumulation of fuels and drought. In order to better understand dynamics of the vulnerability systems, we have evaluated the four wilderness fire syndromes to ENSO events. First, we needed to provide a relative measure of where each case study syndrome falls in conceptual vulnerability space (Table 2). The Fire Modelling Institute of the USDA's Fire Sciences Laboratory has developed national geospatial data (1 km resolution) on fire regimes, current fire regime condition classes, and risks to structures (USDA Forest Service Rocky Mountain Research Station 1999). These data offer comparative measures of exposure and sensitivity, even though these coarse-scale data were developed for national scale planning. Adaptation can be measured by simply looking at the numbers of dollars spent through the National Fire Plan, although we are unable to identifying the regional geographic expressions of those dollars and their on-the-ground effectiveness toward National Fire Plan goals of reducing wildfire risks. Although the data sources admittedly have problems, we are confident that they are useful for understanding wildland fire within a vulnerability framework and identifying options for collecting and developing more detailed data sources.

Table 2: Vulnerability Measures

Study Site	Total GIS area (ha)	Private GIS area (ha)	Total designated Wilderness and NPS area (ha)	Exposure Proxy	Sensitivity Proxy	Adaptation Proxy
GYE	15,541,284	4,758,583	2,548,568	0.100	0.002	$25,025,144
COF	1,231,505	665,561	162,533	0.261	0.077	$70,421,824
LOS	1,484,830	493,177	13,687	0.442	0.086	$77,353,408
MOG	3,343,991	564,806	244,196	0.769	0.063	$86,442,633

The effects of ENSO are not geographically uniform across the western United States. In the southwestern United States La Nina (cool phase of ENSO) events correlate with decreased winter and spring precipitation. These drier conditions favor the ignition and spread of fire, and correlate with historic fire events. In contrast, El Nino events correlate with increased precipitation in the southwestern U.S., decreasing the risk of large wildland fires. In the Colorado Front Range, however, large historical fires correlate with

a lag of 2-3 years after strong El Ninos that increase the accumulation of fine fuels. The Yellowstone area, in contrast, has relatively mild impacts from ENSO events. For the four case studies, we have simplified ENSO interactions with wildland fire (Table 2).

Table 2: Simplified ENSO relationships to fire

	El Nino	La Nina
LOS	Decreased fire risk	Increased fire risk
MOG	Decreased fire risk	Increased fire risk
COF	Increased fire risk, lag	Increased fire risk
GYE	Neutral	Neutral

A graphical depiction of ENSO driven shirts in vulnerability provides insights into how regions differ in their vulnerability as related to wildland fire management (Figure 2). The Greater Yellowstone Ecosystem not only ranks low in sensitivity and exposure but also is relatively insensitive to changes in climate driven by ENSO. Forests in and around the Mogollon Rim, Los Alamos and the Southwest in general rank high in exposure and sensitivity and exposure is heighten under La Nina conditions. The Colorado Front Range experiences increased exposure in the several years following a La Nina event. Most importantly, the graphical depiction of vulnerability dynamics emphasizes that adaptation can be achieved by decreasing exposure and/or sensitivity and that trade-offs should be considered among the biophysical, institutional and cultural aspects of this system.

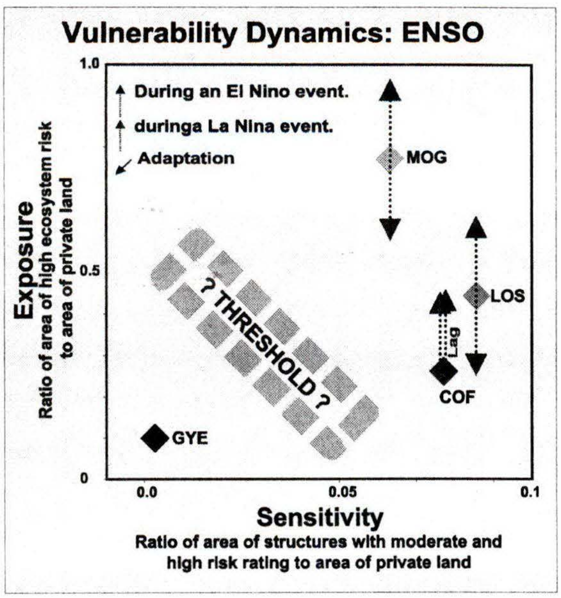


Figure 2. Graphical depiction of vulnerability of four different landscapes as a function of relative sensitivity and exposure and as affected by ENSO-driven climate variability.

Summary and Conclusions

Wildland fire operates within a complex system of coupled human and biophysical factors and feedbacks. Our framing of this system in terms of vulnerability and syndromes offers concepts that can inform how we assess options for fire in and around wilderness and natural areas. In particular, this framework emphasizes adaptation as a feedbacks that may strongly influence management options. In particular, long-term adaptation of individuals and communities may alter either exposure (e.g., fuels reduction) or sensitivity (e.g., firewise homes, land use zoning for fire hazards). Whether or not adaptation results in risk reduction that is significant enough to allow natural fire in specific geographic areas is unknown.

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Section 3. Climate Change and Wilderness Management: Emerging Issues

Overview. This section summarizes the presentations and discussion that took place at a half-day workshop entitled Managing Wilderness and Other Natural Area for Climate Variability and Change, held on October 5, 2005 in conjunction with the 8th World Wilderness Congress in Anchorage, AK. The workshop was organized by Lisa Graumlich with assistance from Steve Gray (Desert Laboratory US Geological Survey). Dave Parsons (Aldo Leopold Wilderness Research Institute, US Forest Service) and Nate Stephenson (Sequoia and Kings Canyon Field Station, US Geological Survey).

The context of the workshop was the growing recognition that the impacts of global change are being registered worldwide in warming temperatures, shrinking snowpack and glaciers, and changes in the frequency of disturbances, including fires and severe storms. Climate change poses a particular challenge to wilderness managers because of their mandate to conserve natural conditions.

The objectives of this workshop are 1) to provide an update of key science issues associated with climate change and variability; and 2) to open a dialog on strategies for managing wilderness in the context of global change.

Participants were recruited from senior management levels in national parks and wilderness areas in western North America. The participants represented a broad spectrum of ecoregions (see list of participants appended at the end of the report).

Content presented. Formal presentations covered the following topics:

- Arctic Climate Change: A worst case scenario? (Graumlich). Why is global climate change most strongly expressed in the Arctic? How do feedbacks accelerate climate change and its impacts? What can we learn from the Arctic that is relevant to management of temperate zone wilderness areas?

- Climate Change in the Mid Latitudes: Can small changes in climate have significant impacts on wilderness and natural areas? (Gray) How do we best deal with uncertainties in forecasts for future change? How can relatively small changes in climate can have large consequences for natural (physical and biological) systems? Why must persistent droughts should be considered as a key feature of mid-latitude climate variability?

- Anticipating Change: How can management strategies promote resilience in the face of climate change? (Stephenson) How might climatic changes

interact strongly with other drivers of change? How might threshold responses lead to surprises?

Key points from discussion. The participants listed the following issues as priorities and critical gaps in information for their agency and situation. In this report, I have grouped them into broad categories.

Gaps in knowledge

- What are likely scenarios for the future?
- What is the evolutionary capacity of species and ecosystems in the face of climate change?
- What is the utility of climatic forecasting tools?
- What tools and concepts allow us to distinguish natural vs. human induced change?
- How can we best recognize and deal with rapid change?
- How do we best anticipate the indirect effects of climate change?
- How does climate change interact with fire?
- How is climate change likely to impact large migratory animals?

Management strategies:

- How can we work with different models of protection of resources?
- How do we formulate optimal "no regrets" policies?
- How best can we work within framework conventions and international agreements to create viable adaptation strategies for native peoples?
- How do we best take advantage of parks and protected areas as venues for public education?
- How do mandates associated with park or wilderness status limit options for management in the face of climate change?
- How can we best manage for climate change impacts on subsistence issues?
- How does climate change impact our abilities to manage endangered species?
- How can we achieve better real time information to facilitate rapid and flexible decisions?

Discussion centered on several key ideas, including

- Protected areas could be transformed into floating reserves which promote connectivity. Private lands are key to this concept.

- Managers will increasingly need to face and justify whether to intervene or not in the face of climate change.
- The old management paradigm suggested that prediction leads to control. The emerging paradigm suggests that management must work within changing targets, natural variability and adaptive management
- Management in the face of climate change must seek to avoid catastrophic outcomes, buffer against extremes, and foster no regrets policies
- Actions outside wilderness areas will be critical to maintaining wilderness. This is especially true for fire.
- Decision making must increasingly involve stakeholders, especially to mitigate risks as perceived by stakeholders

The results from the discussion are being developed as a manuscript for submission to the *International Journal of Wilderness*.

Managing Wilderness and Other Natural Areas for Climate Variability and Change

Wednesday, October 5, 2005, 1:30 to 5:30 pm
8th World Wilderness Congress
Room B, Egan Center
Updated: May 11, 2006

Workshop Leaders

Lisa J. Graumlich
Executive Director, Big Sky Institute for Science and Natural History
Montana State University
106 AJM Johnson Hall
Bozeman, MT 59717
Phone: 406-994-5320
Fax: 406-994-5122
Email: lisa@montana.edu
www.bsi.montana.edu

Stephen T. Gray
Postdoctoral Research Associate
Desert Laboratory
U.S. Geological Survey
1675 West Anklam Road
Tucson, AZ 85745
Phone: 520-670-6821 ext. 119
Email: stgray@usgs.gov

David J. Parsons
Director, Aldo Leopold Wilderness Research Institute
790 E. Beckwith Ave.
Missoula, MT 59807
Phone: 406-542-4193
Fax: 406-542-4196
Email: djparsons@fs.fed.us

Nathan L. Stephenson
Research Ecologist, USGS Western Ecological Research Center
Sequoia and Kings Canyon Field Station
47050 Generals Highway #4
Three Rivers, CA 93271
Phone: 559-565-3176
Fax: 559-565-3177
Email: nstephenson@usgs.gov

Participant List

Gregory H. Aplet
Senior Forest Scientist
The Wilderness Society
1660 Wynkoop Street, Suite 850
Denver, CO 80202, USA
Phone: 303-650-5818 x104
Fax: 303-650-5942
Email: greg_aplet@tws.org

Susan Boudreau
Chief of Resources and Research
Glacier Bay National Park
P.O. Box 140
Gustavus, AK 99826-0140
Phone: 907-697-2640
Email: susan_boudreau@nps.gov

Ryan Danby
PhD Candidate
Department of Biological Sciences
University of Alberta
Edmonton AB Canada T6G2E9
Phone: 780-492-1295
Email: rdanby@ualberta.ca

Nancy Descher
Hydrologist, NPS (retired)
Phone: 907-243-8581
Email: nancyd@alaska.net

Tim Devine
Park Service Representative
Arthur Carhart National Wilderness Training Center
James E. Todd Building,□32 Campus Drive
Missoula, Montana 59812-3168□
Phone: 406-243-4612
Fax: 406-243-4717
Email: tim_devine@nps.gov

Gregg D. Fauth
Wilderness Coordinator, National Park Service
Sequoia and Kings Canyon National Parks
47050 Generals Highway
Three Rivers, CA 93271
Phone: 559-565-3137
Email: gregg_fauth@nps.gov

Phyllis Green
Park Superintendent
Isle Royale National Park
Houghton MI 49931
Phone: 906-487-7140
Email: Phyllis_Green@nps.gov

Philip N. Hooge
Asst. Superintendent for Resources, Science and Learning
Denali National Park
Denali Park, AK
Phone: 907-683-9581
Email: Philip_hooge@nps.gov

Danielle G. Jerry
Chief, Division of Natural Resources
National Wildlife Refuge System, Alaska Region
U.S. Fish and Wildlife Service
Phone: 907-786-3335
Fax: 907-786-3905
Email: Danielle_Jerry@fws.gov

Sonja Krüger
Ecologist, Ezemvelo KZN Wildlife
P.O. Box 13053
Cascades 3202
South Africa
Email: skrueger@kznwildlife.com

Kevin Larkin
Asst. Rec. Program Leader
White Mountains Nat. Forest
Laconia NH 03246
Phone: 603/528-8951
Email: klarkin@fs.fed.us

David D. Mills
Superintendent, Gates of the Arctic National Park and Preserve
Yukon-Charley Rivers National Preserve
Phone: 907-457-5752
Email: david_mills@nps.gov

Carol Miller
Research Ecologist, Aldo Leopold Wilderness Research Institute
790 E. Beckwith Ave.
Missoula, MT 59807
Phone: 406-542-4198
Fax: 406-542-4196
Email: cmiller04@fs.fed.us

Rebecca Oreskes
Program Manager
White Mountain National Forest
300 Glen Road
Gorham, NH 03588
Phone: 603-466-2713, extension 212
Fax: 603-466-2856
Email: roreskes@fs.fed.us

Duncan Purchase
Assistant Director, Zambezi Society
P.O. Box HG 774
Highlands, Harare, Zimbabwe
Email: duncan@zamsoc.org
dnp@mweb.co.zw
Phone: 263-0-91-242-272
263-0-91-242-837
www.zamsoc.org

Craig Reid
Conservation Manager, Imfolozi Game Reserve, South Africa
Phone: 035 5508481
5508200
Email: reidc@kznwildlife.com

Bud Rice
Environmental Protection Specialist
National Park Service - Alaska Region
240 West 5th Avenue
Anchorage, Alaska 99501
Phone: 907-644-3530
Fax: 907-644-3814
Email: bud_rice@nps.gov

Farida Shahnaz
Programme Officer
IUCN
Bangladesh Country Office
Gulshan1, Dhaka 1212 Bangldesh
Phone: 880-2-989-0395
Email: shahnaz@iucnbd.org

John Shultis
Associate Professor
Resource Recreation & Tourism Program
University of Northern British Columbia
Prince George BC Canada V2N 4Z9
Phone: 250-960-5640
Email: shultis@unbc.ca

Sandra Victoria Silva
Environmental Engineer
6228 South Coventry Lane West
Littleton, CO 80123
Phone: Day 303-914-3801
Evening 303-797-1549
Email: sandra_v_silva@fws.gov

Susan Skaalid BSc., MSc., GDBA
Manager, Forest Operations
Forest Management Branch,
Yukon Government
Phone: 867-633-7904
Fax: 867-667-3138
Email: susan.skaalid@gov.yk.ca

Adrian Stokes, PhD
Senior Ecologist, Ecological Restoration
Science & Conservation Directorate
Department for Environment and Heritage, South Australian Government
GPO Box 1047
Adelaide, S.A. 5001 AUSTRALIA
Phone: 61-8-8222-9420
Fax: 61-8-8222-9456
Mobile: 0417-010-360
Email: stokes.adrian@saugov.sa.gov.au
www.environment.sa.gov.au

Ruth Waldick
Habitat Conservation Specialist
National Wildlife Research Center
Environment Canada
Ottawa Ontario Canada K1A 0H3
Phone: 613-998-7314
Email: Ruth.Waddick@ec.gc.ca

Mike Walton
Manager, Corporate Affairs/Gestionnaire, Affaires ministérielles
Environment Canada, Yukon
91780 Alaska Highway
Whitehorse, Yukon Y1A 5B7
Email: Mike.Walton@ec.gc.ca